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IITRI FINAL REPORT C06538

TOTAL SYSTEM HAZARDS ANALYSIS FOR THE WESTERN AREA DEMILITARIZATION FACILITY AT HAWTHORNE ARMY AMMUNITION PLANT

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Prepared for

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December, 1982

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FOREWORD

This is the final report on Contract No. DAAA09-81-C-3006 conducted by IIT Research Institute, Chicago, Illinois, for the U.S. Army ARRCOM, Rock Island, Illinois. This report describes the results of a hazards analysis of the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. The project was divided into three segments (priorities) and detailed reports have been submitted describing the analyses and results for each priority. The Priority 1 Report, covering the Steam and Hydraulic Systems, was submitted during July 1982. The Priority 2 Report, covering the Preparation Building, the Accumulator, the Mechanical Removal Building, and the Large Cells, was submitted during November 1982. The Priority 3 Report, covering the Decontamination Building, the Large Items Flashing Chamber, the Driverless Tractor System, the Offloading Dock, and the Magazines, was submitted during December 1982 concurrent to this report.

Members of the IIT Research Institute staff who contributed significantly to this project include Dwayne Eacret, Charles Heilker, Cindy Marrazzo, Kim Mniszewski, Ronald Pape, and Edmund Swider. Mr. Thomas Grady, a private consultant with considerable experience in explosive and propellant operations, helped scrutinize the results of the analyses and provided many valuable suggestions.

Respectfully submitted

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1. INTRODUCTION

In this report, the results of a hazards analysis of the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada are summarized. The details of the analyses are provided in three reports (references 1, 2 and 3) and are not repeated in this document. Each of the detailed reports consists of two volumes. Volume 1 is a summary of the analysis results with appendices covering special problem areas. Volume 2 contains fault tree diagrams for each of the plant areas that were evaluated. This final report contains an overview of the WADF systems (Section 2), the hazards analysis methodology that was applied (Section 3), a discussion of the quantitative fault tree results in terms of the 95 percent confidence level (Section 4), and a compilation of the conclusions and recommendations for each area of the facility (Section 5). The recommendations have been prioritized in section 6 (refer to Table 2 on pages 50-54). Recommendations with rankings of 6 to 10 are considered to be crucial and should be implemented, or at a minimum critically evaluated.

2. OVERVIEW OF THE WESTERN AREA DEMILITARIZATION FACILITY

The Western Area Demilitarization Facility (WADF) was designed "to demilitarize obsolete, out-of-date, or unserviceable conventional ammunition items by safe, economical, and environmentally acceptable techniques" (ref. 4). The volume of such material that should be disposed of is increasing significantly and must be dealt with. Costs associated with storage (space, record keeping, and security) are increasing. Existing facilities are not easily adapted to handle the required production rates.

The facility at Hawthorne, Nevada was initially designed under the Naval Facilities Engineering Command, Western Division, and has since been transferred to Army responsibility.

The WADF system consists of the Off-Loading Dock, Driverless Tractor, Preparation Building, Accumulator Building, Mechanical Removal Building, Large Cells, Washout/Steamout Building, Process Water Treatment Facility, Bulk Explosives Disposal Building, Refining Building, Flashing Chamber, and the Decontamination and Small Items Building. These were evaluated for hazards under three priorities. Priority 1 included the "wet systems" (Washout Steamout Building, Refining Building, Bulk Explosives Disposal Building, and the Process Water Treatment Plant). Priority 2 included the Preparation Building, the Mechanical Removal Building and the Large Cells. Priority 3 contained the Decontamination Building, the Large Items Flashing Chamber, the Driverless Tractor System, the Off-Loading Dock, and the Magazines. These systems are described in the paragraphs below.

2.1 PRIORITY 1 SYSTEMS

Washout/Steamout Building

The Washout/Steamout Building consists of two towers separated by a support area containing a boiler room, steam room, and chemical laboratories. This facility is for wet removal of explosives (i.e., by steam and hydraulic processes). There are four categories of wet processes. First, for TNT or similar single

phase meltable explosives, the material is melted by contact with a steam jet. It is drained from the item, de-watered, formed into dry flakes and packaged. This procedure is accomplished in the Steamout Building--North Tower. Second, for explosive D or other similar relatively soluble explosives, hot low pressure water is used to hydraulically wash out the material (by erosion and solution). The material is directed into a large transportable container for subsequent disposal at the Explosives Disposal Building. This operation is accomplished in the Washout Building--South Tower. For Composition A3 or similar press loaded explosives, a very high pressure (10,000 psi) water jet is used to break up the material by erosive action. The material is flushed out of the item, de-watered, and packaged. This operation is also accomplished in the South Tower.

The Washout Building (South Tower) holds two washout chambers at the top levels of the tower. The large items washout chamber is for 8 inch and 16 inch projectiles only. This chamber uses a lower pressure hot water lance to erode and dissolve out explosive D or similar materials from items. The medium caliber indexing table handles smaller munitions items (containing explosive D or A3) two at a time. High pressure (10,000 psi) water lances are used to erode out the material in two steps. Explosive D from either washout device is dropped into a settling tank and ultimately loaded into movable tanks for transport to the Explosives Disposal Building. Explosive A3 is loaded onto a vibrating screen dryer to remove the majority of the water. It then is passed through a belt air dryer prior to packaging.

In the North Tower large items containing TNT and HBX (possibly Tritonal and H6 also eventually) are handled. Currently, this includes items such as M16, M25 and M39 mines, but may also include bombs eventually. The items are hoisted to the top level of the tower and strapped onto tilting tables. The tables are put in a 45° incline so that the operator on the next level down can insert a lance into each item. As the material is drained out of the item, the operator manually advances the lance. The operation can take up to 8 hours to complete. After steamout is complete, the tables are brought back to horizontal position, the item is then hoisted up and put into one of

four autoclaves to melt out the asphalt liner and any residual explosive. The explosive removed from the items flows into a storage kettle. From there it goes to a steam jacketed kettle for metering onto a belt flaker. The melted asphalt and residual explosive flows to a kernelling machine where the contaminated asphalt is solidified into globules for disposal.

Water Treatment Facility

The Process Water Treatment Facility sits adjacent to the Washout/Steamout Building. This is a fairly conventional system for water treatment. Feed is added to the clarifier with alum and polymer. The alum coagulates substances in the water. The polymer aids coagulation. The coagulation-flocculation begins with a rapid mix in the top and gentler mixing in the mid region. The agglomerated particles settle to the bottom and are removed with positive displacement pumps. The sludge from the bottom is only about 5 percent solids and is dewatered further in the sludge basins. The clarified water is then filtered. The effluent turbidity is monitored (from sand filters) and backwashing of the filters is initiated when the turbidity is too high. The sand filters remove any floc particles which have not settled from the chemical precipitation. The activiated carbon columns remove organics. When the pressure gradient through the carbon columns becomes too high, either the media will be replaced or backwashing will be done. The pH of the water can be from 9 to 11; therefore, H_2SO_4 is added and mixed with an in-line static mixer. The final pH should be in the range from 6-8.

Refining Building

The Refining Building is to be used for removal of melt-cast explosives from projectiles (small items, up to 7.2 in. depth charges). The exterior of the shell is exposed to pressurized superheated steam (dry thermal process from the standpoint of the explosive). The items are positioned into a holding fixture designed to prevent the steam from entering the item and contacting the explosive inside. The items are then hoisted up and lowered into one of the autoclaves in the Refining Building. As the explosive melts, it is drained through the bottom of the autoclave unit into a steam jacketed holding tank. The liquid explosive is then fed into strands onto a stainless steel

belt flaker. It cools and solidifies on the belt and is broken up into flakes at the exit end of the unit. The flaker unit is hooded to remove fumes and is protected by UV detectors used to trigger a water deluge. The flakes are metered by vibratory conveyor into a weigh unit and packaged for shipment or storage.

Bulk Explosives Disposal Building

Non-saleable energetic materials, such as explosive D and those double and triple base propellants that cannot be sold, are handled at the Bulk Explosives Disposal Building. Containers holding the material are conveyed into the slurry preparation area. The container contents are dumped into the feed hopper for the grinder. The feeder conveyer passes the material through a metal detector prior to discharge into the grinder. In the grinder, the material is ground, with water injection, into small pieces, and passed into the slurry tank. A slurry consisting of a 3:1 mixture of water to solids by mass (monitored by slurry density) is prepared in the slurry tank and then transferred to the adjacent cell of the building. The slurry is circulated in a loop at about 25 gpm between the feed tank and one of the two incinerator units outside of the building. It is bled off from the loop at about 7 gpm and injected into the oil fired rotating drum incineration unit. The primary incinerator section is a drum furnace rotating at 3 rpm. The combustion products then pass through an afterburner and exhaust stack.

2.2 PRIORITY 2 SYSTEMS

Preparation Building and Accumulator

Mechanical disassembly of items is to be performed in the Preparation Building in individual cell areas of the building. Processes include (1) pull apart of elements joined by crimping (e.g., removing the projectile from the cartridge case); (2) unscrewing the parts such as fuzes from projectiles, rocket motors from warheads, or fuzes and fin assemblies from mortar cartridges; (3) removal of propellant from cartridges; and (4) removal of primers from cartridge cases. The Preparation Building cells are to handle gun type ammunition up to and including 6 inch. There are six work cells in the building. Each cell has 4 UV detectors and a preprimed (wet) water deluge system. Operations are monitored by closed circuit TV. Currently cells 1 and 2 are not equipped.

Cell 3 is currently for breakdown of 60 mm and 81 mm mortar cartridges. Two rounds at a time are placed on a holding fixture (steel plate shuttle) in front of the cell by an operator. At the proper time, the holding fixture is indexed into the cell through an access port. Once inside the cell, under the watchful eyes of the control operator, the previously disassembled two rounds are picked up by the robot (manipulator) at the disassembly "lathe" and placed in the holding fixture. Next the robot picks up the complete rounds and brings them into clamping position at the "lathe". With the rounds held firmly, the chucks on either side of the cartridge unscrew the fuze on one end and the tail fin on the other end. The head and tail units are then automatically picked up and dropped into water filled containers sitting next to the machine. The mortar body is carried by the manipulator to the shuttle conveyor to the corridor outside the cell.

Cells 4, 5, and 6 are dedicated to disassembly of gun ammunition. A conveyor from the corridor carries projectiles and cartridge cases into Cell 5. In Cell 5, a pull apart machine removes the projectile from the cartridge case on fixed munition. For plugged cartridge cases, when the shell and case are separate (separate gun ammunition) the pull apart machine is replaced by an end cut off machine which removes the end of the case by using a tube cutter type device. In that case, the projectile enters Cell 5 separately and goes directly to Cell 6. In Cell 6, an unscrewing machine, just like that in Cell 3, is used to remove fuzes and base fuzes.

The cartridge cases are moved by the robot from the tube cutting device into a horizontal position for the removal of a wad prior to dumping of the propellant. The propellant is dumped from the cases onto a conductive rubber belt conveyor to be carried to the accumulator building. Then the cartridge case is shuttled into Cell 4 via a conveyor. In Cell 4, the cartridge case is automatically placed into a fixture to punch out the primer in its base. When the cartridge case is conveyed back into the corridor, the operator must manually remove the primer from the inside of the case.

As mentioned above, the propellant removed from the cartridge cases is conveyed to the Accumulator Building. The conveyor is enclosed and protected with UV sensors, and deluge nozzles every six feet. At the accumulator, the

receiving storage hopper is equipped with two high-level sensors, the lower one to stop operations in Cell 5 of the preparation building and the upper one to stop the conveyor motion. The material is routed from the storage hopper to a vibratory feeder conveyor and finally to a weigh hopper. The propellant is then metered into type III or MK IV containers for storage or sale. Two bag collector units service the preparation and accumulator buildings. In addition, a vacuum system is available for special cleanup operations. Four vacuum cleaning units each consist of a cyclone separator, wet collector and dry collector. These are housed in the cells immediately adjacent to the central propellant packaging cell. The outermost cells hold the pumps used to pull the air through the vacuum collection units.

Mechanical Removal Building

The mechanical removal building contains equipment used to expose the interior of conventional munition items and to provide access for explosive removal processes. Also, in some cases on large munitions, the facility is used to provide vent/view holes in the item to facilitate inspection of the items prior to flashing them of residual materials in the flashing chamber. The operations include trepanning (hole cutting), sawing, shearing and punching of holes in munition items. Before entering the mechanical removal building, some items are washed/steamed out leaving only small amounts (under ten pounds) of explosive in them, with acceptance determined by visual inspection, while other items are fully loaded.

Forklifts are used to move items from the conveying vehicle (driverless tractor and carts) into the building where jib cranes are employed at the corridor-to-cell port of each cell. On all large or heavy items jib cranes are used to place items onto carriages/tooling which convey the items into cells for processing on"through-port" conveyors.

All operations in the cells are controlled remotely by operators in the control room of the building. Cell 1 houses equipment used for punching holes in, or shearing, relatively small munition items (such as MK1 boosters or MK42 primers) containing appreciable amounts of energetic material. Ammunition items are mounted on tooling carrier plates that ride on a conveyor. Clamping

elements hold the tool carriers in a predetermined position in the press accurately and positively for shearing and/or punching. Presently primers longer than 8 inches are to be sheared into smaller pieces using an industrial-type hydraulically operated press.

Cell 2 contains a band saw for sawing items 25 inches in diameter or less. Presently the MK 4 depth charge noses are to be sawed off by the band saw to expose the explosive charge for easier removal. The items are clamped to a tooling carrier which rides on a conveyor between the band saw and the corridor. A powered-roller conveyor is used together with a ball transfer table to manipulate the tooling carriers. Holding clamps fix the tooling carrier accurately and positively in a predetermined position while sawing is underway.

Cell 3 holds trepanning (hole sawing) equipment to cut a series of 5 inch diameter vent/view holes simultaneously in large munition items. A special hole cutting machine, equipped with a shuttling carriage, a deep bed filter and an aspirator is applied in Cell 3 to produce the vent/view holes. The shuttling carriage rides on two-section ways, one section inside the cell and the second section in the corridor. The hole cutting machine consists of a framework on which six horizontally oriented, hydraulically powered spindle heads are mounted in parallel. A hydraulic cylinder on each head provides the stroke. A "slug" ejection device is provided on each head to push the cut-out portion of the items out of the hole saw and into the item being processed. In conjunction with the heads six horizontally oriented, hydraulically actuated backstop units are provided. The purpose of the backstop units is to resist the force applied by the heads during the cutting operation.

An aspirator is included as part of the hole cutting equipment to remove the coolant accumulated in the interior of the item during hole sawing. Coolant is removed from the item when it is returned to the corridor. In special cases should additional vent area be required or should view openings in other places be required, after the first array of holes are cut and the item retracted to the corridor, the clamps holding the item can be released, the item rotated on the carriage, reclamped, and reintroduced to the cell for the cutting of another set of holes in a second plane.

At the time of the hazards analysis the major cells were operational and equipped with the appropriate machines, conveyors, tooling/fixtures, and jib cranes or assist devices. Two smaller cells and an extra room are located in the Mechanical Removal Building on the same side of the corridor as the operational cells. Across the corridor from the cells is the mechanical room housing all equipment and utilities necessary for the operation of the building. Also, the control room is located across from the cells, housing the controls necessary to remotely operate the equipment in the cells together with CCTVs* to observe the operation in each cell.

Large Cells

Three large cells (constructed with frangible walls and ceilings due to the hazardous operations performed on large munitions) are located adjacent to the mechanical removal building. These house machines used in disassembly operations for large munitions items. Two of these cells are currently in use. Cell B is set up for cutting open MK 16 mines using a band saw. Cell C contains an unscrew machine for defuzing major caliber munition items. Cell A is presently empty and could be used for temporary storage (within allowable charge weight envelopes) of large munition items. These cells are serviced by an over-head bridge crane system to move the large munition items in and out of the cells.

2.3 PRIORITY 3 SYSTEMS

Decontamination Building

This building contains three furnaces to decontaminate various items. First, a rotary type furnace is used for small arms ammunition containing lead. The items are placed into a rotating dumper and transferred into a conveyor which carries them to the furnace feeder. The lead items furnace is a rotary type oil burner furnace. At the burner end, a narrow opening is left between the furnace and burner flanges for liquid lead (1) to drip into a trough, (2) be carried to a water bath for cooling and (3) then be carried by conveyor to a hopper for subsequent removal by truck. The remaining refuse from the

* Closed Circuit Televisions

furnace is deposited onto a second conveyor and carried to a magnetic (ferrous/nonferrous) separator where it is directed into a "ferrous or nonferrous" semi-trailer positioned under the separator chute.

A second rotary furnace, the detonating items furnace, is quite similar to the lead items furnace. This incinerator does not have the spacing between flanges at the burner end since liquid lead is not to be removed. A separate conveyor is used to recycle some of the refuse to maintain the proper depth of material in the furnace body. Since this furnace must withstand items detonating within, the walls are stronger than the lead items furnace, and the center section is recessed to increase the residence time of the items near the center of the cylinder.

The fifth and sixth cells in the decontamination building house the tray type flashing furnace. Here, moderate sized processed items (cleaned out), which can be inspected to preclude presence of a significant amount of energetic material, will be decontaminated. Items will be processed through a conventional heat-treating type furnace (fire brick walled) where they will be heated to a temperature at which any residual energetic material decomposes or burns. Typical items to be processed include rocket warheads (e.g. 2.75 in., 5.0 in.), depth charge warheads (e.g. MK4, MK5), and gun ammunition projectiles (e.g. 40mm through 5"/54). Items are loaded into trays in the loading area, either manually or with the help of a mechanical assist. The trays are then loaded through a blast lock into the furnace. Four trays are continually present in the furnace. At intervals of approximately 7 1/2 minutes, a new tray enters and a processed tray leaves the furnace where it is checked for proper final temperature conditions. Then it is raised on a skip loader where the items are dumped into a dumpster. Trays are returned by first being cooled in a water spray chamber and then sent into the tray loading area for recycling, by means of conveyor equipment.

<u>Large Items Flashing Chamber</u>

In the flashing chamber, smokeless powder is used to burn off residual explosive left in larger items from which the bulk of the explosive already has been removed. Decontamination of these items is required before the metal components can be sold as scrap. Deactivation and/or decontamination of con-

taminated items has been accomplished in the past primarily by exposing the material to a high temperature for a prolonged time such that the energetic material decomposes, burns or detonates. This is accomplished by placing the items in a bonfire in a field burn. Short duration high temperature exposures have also been used in the past by placing smokeless powder in the internal cavities of the item and igniting the powder. According to the Batelle report (reference 4), such flashing "has been found to be effective in completely destroying residues of explosive on or in the ammunition items". As discussed in the results section, there is some question as to whether flashing really will be effective in all cases due to the shortness of the high temperature pulse.

At WADF flashing is to be accomplished inside a containment chamber designed to prevent products of combustion from escaping to the atmosphere. It is designed to maintain structural integrity in the event of the detonation of a 120 lb (TNT equivalent) line charge along the chamber's axis. During a burn, the combustion products are ducted underground to a regenerative heat exchanger (a mass of steel tubes) and to a bag house for pollution control.

Pneumatically driven mine cars are to be used to carry the contaminated items from the DLT (item receiving area) into the car preparation enclosure, where the smokeless powder is layed, and then into the flashing furnace. A narrow gage track loop routes the mine cars into the chamber and then back out to a cool off area. A massive door covers the chamber's entrance during a burn. and all personnel are to return to the Decontamination Building at that time.

Driverless Tractor System

A driverless tractor (DLT) and ammunition cart system utilizing Prontow 601 vehicles has been installed at WADF. Two independent DLT control systems are present. One network (Region 1) moves tractors between the Off Loading Dock and the Preparation Building. The second network (Region 2) moves tractors between the Preparation Building and the various Process buildings at the site. The battery powered tractors are guided by a low frequency signal transmitted from wires layed in slots cut in the concrete guide paths. An amber strobe light indicates when a vehicle is operating automatically. A horn sounds on all automatic starts and stops. Dynamic braking of the

vehicle is accomplished by means of the traction motor. A safety bumper is attached to the front of the tractor which actuates an emergency stop if it contacts a person or other object. High pressure Nitrogen or air supplies power for quick braking of the train. A DLT train consists of a tractor and one to four carts, the total live load being up to 22,500 pounds. The minimum train speed is 2.5 mph and the maximum speed is 3.5 m.p.h. The tractors can be operated in either the automatic mode while on the guide paths or in the manual mode of operation. In the manual mode the operator stands on the cart. A deadman switch must be depressed as the vehicle moves in this mode. The vehicle is accelerated using a foot pedal with several discrete speed positions.

Off Loading Dock

Munitions items to be demilitarized enter the facility at the Off-Loading dock. The Off-Loading dock is a conventional earth covered unloading structure designed to handle delivery of energetic materials by train or truck. It consists primarily of two adjacent earth covered tubes for unloading trains, but also has unprotected docks next to the igloo type structure. Items are to be taken from the unloading dock to the preparation building via the driverless tractor system.

3. METHODOLOGY

Each of the Priority Reports contains a section or appendix describing the methodology used in conducting the hazards analyses. The methodology is repeated here to aid the reader in understanding the meaning of the results obtained.

Basically, the following steps were used in the analyses:

a) Collect Available Information
b) Review Information/Learn System
c) Conduct an Informal Failure Modes and Effects Analysis (FMEA)
d) Develop Fault Tree Logic Diagrams for System (FTA)
e) Quantify Fault Tree (derive scenario probabilities)
f) Interpret and Summarize the FTA Results

For the purposes of this program, the failure modes and effects analyses served to identify types of consequences and types of scenarios to be expected in different areas of the WADF. The FMEA's were used to learn the system and guide the development of the fault trees. Fault tree analysis was the primary methodology used to identify and quantify credible hazards at the facility. The FMEA and Fault Tree methods are described below:

3.1 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis is a relatively simple and direct approach for identifying basic sources of failure and their consequences. This method is not rigid and can be used for widely differing applications. It is especially applicable for identifying sources of malfunctions in hardware systems or in process equipment. The primary purpose of the analysis is to identify and remove failures that can cause hazards. However, as a side benefit, the analysis also leads to the identification of failures that are in themselves not hazardous but might affect the reliability of the functioning of a system. The results of such an analysis also may serve as an input to a Fault Tree Analysis, although more generally the two methods are used independently.

A Failure Modes and Effects Analysis is carried out by filling in a table having column headings such as the one shown in Figure 1 . This format is the one used for the Priority 1 systems. The first two columns list the system parts and procedure steps obtained from the available drawings, written descriptions, etc. The third column is used to identify the different possible failure modes for each entry listed in the previous columns. There may be several entries in column 3 for each system part or task. Given these initial failures, the possible chains of events are described in the next column, and the ultimate effect on the system is given in the last column. The Priority 1 FMEA tables were relatively formal and time consuming to produce. These tables were used primarily as "shopping lists" for fault tree development, a function not necessitating the formal presentation. In Priority 2 and 3 analyses a less formal FMEA presentation was utilized, although FMEA was still used to provide the basis for the fault tree diagramming.

3.2 FAULT TREE ANALYSIS

Fault Tree Analysis is a powerful method that has developed rapidly since 1962. This method may be viewed as a systematic and comprehensive investigation of a postulated accident before it occurs. The term "accident" in this case is used to signify any kind of undesired event. The procedure is to define this undesired event and to identify all immediate causes that could have brought it about. These causes, in turn, are traced back through the system until one arrives at the ultimate causes that initiated the sequence of events that led to the undesired event. These ultimate causes may be failures of individual hardware components, or human errors, or other factors which either singly or in combination could have initiated the hazardous action.

An immediate result of such an analysis is a graphical representation of all basic failures and the paths whereby they can combine to create the undesired event. The method also can be used quantitatively. If data are available for the probability of occurrence of the basic failures, it is possible to calculate the probability of occurrence of the undesired event. In doing so, it is also possible to identify those basic failures that are most critical, and the most critical sets of events (scenarios), so priorities can be established for taking corrective action.

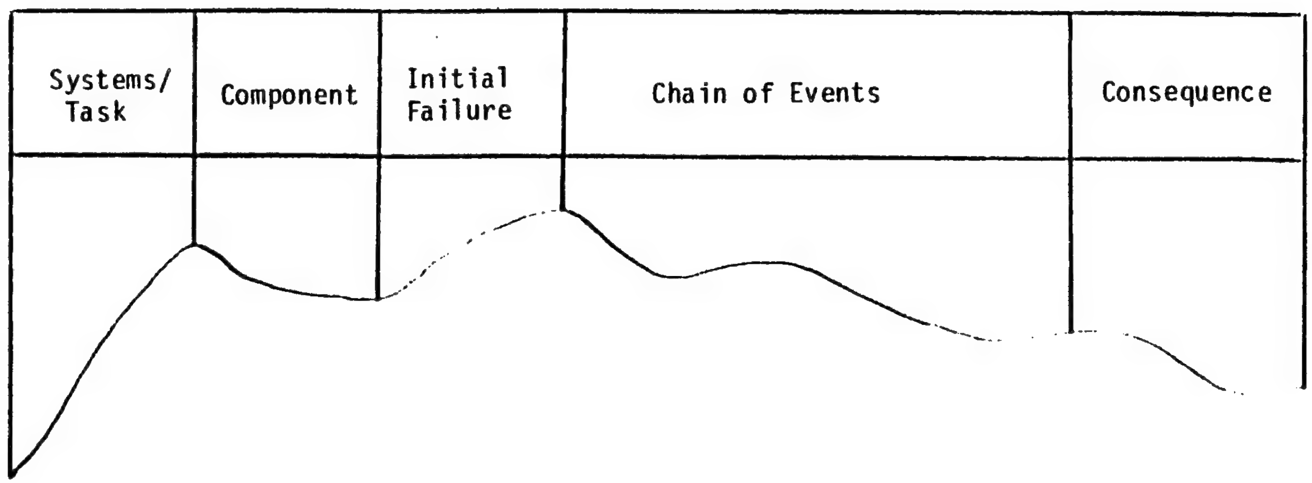


Figure 1 Failure Modes and Effects Analysis Format Used for Priority 1 Systems

An analysis begins by identifying an Undesired Event whose causes are to be traced. Graphically, this event is placed at the top of the page and represents the base of a tree whose branches are developed and extend downward. Once the undesired event, also called a Top Event is specified, it is necessary to identify the immediate causes which directly could cause this top event. Each of these causative events, in turn, is further broken down into subordinate events. This process is continued until one arrives at basic input events that cannot be broken down further, or for which probability data are available so there is no need to go further.

Figure 2 illustrates the diagrammatic arrangement of a fault tree, and Figure 3 identifies the geometric symbolism that is commonly used in fault tree construction. It is to be noted that a fault tree consists of three essential elements -- input events, logic gates, and output events. The basic logic gates are of two kinds, namely OR gates and AND gates. If an output event can be caused by one or more input events, either when each acts by itself, or when they act together, these input events pass through an OR gate. On the other hand, if an output event can be caused only when all input events must act in combination, these input events pass through an AND gate.

This concept is illustrated in Figure 4 where the top event is defined as the lighting of the light bulb. For the circuit diagram which shows all the switches arranged in series, all four must be closed for the light to stay in. In the logic diagram for this arrangement, these four switches are shown connected to an AND gate. In the other circuit diagram, where the four switches are arranged in parallel, it is evident that the closing of any one switch would be sufficient to light the bulb. The logic diagram for this case shows the four input events to pass through an OR gate. If the probability for each of the switches A, B, C, and D remaining closed were known, it would be possible to determine the probability of the bulb remaining lit for each circuit. That is, the symbolic logic relationships can be converted to algebraic expressions for numerical calculation.

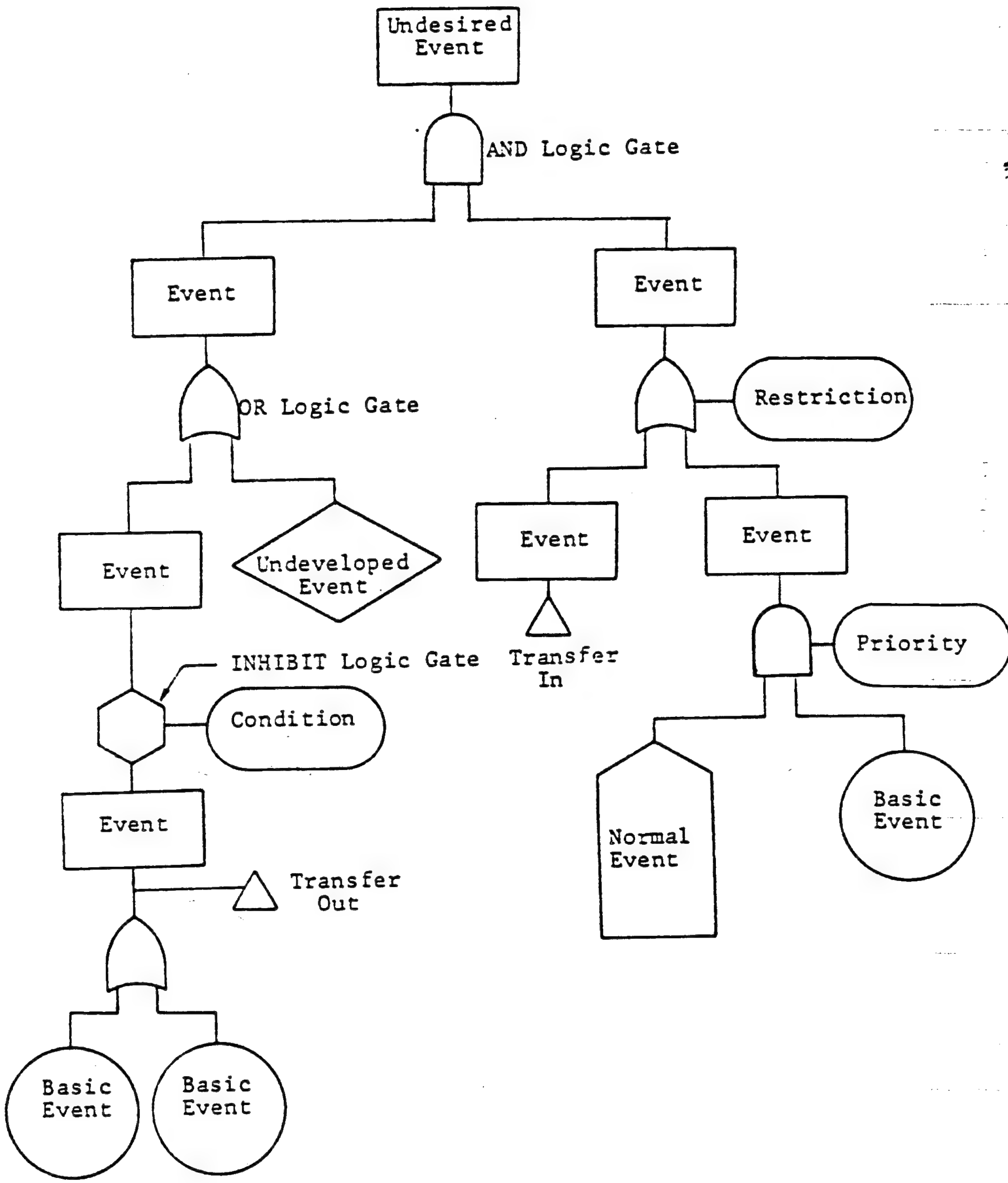
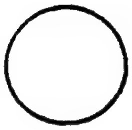
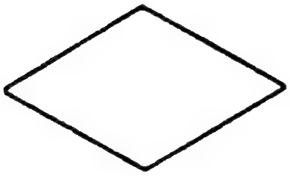


Figure 2 Diagramatic Arrangement of Fault Tree

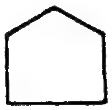
An event caused by one or more other events which are identified



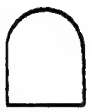
A basic input event that does not require further development as to causes



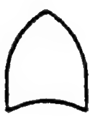
An event which is not developed further as to its causes because of lack of information or significance



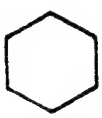
An event which is normal for the system; not a fault or failure per se



AND gate - output event occurs only if all the input events are present



OR gate - output event occurs when one or more of the input events are present



INHIBIT gate - output event is caused by input event only if specified condition is satisfied

Attached to logic gate to specify a condition

Continuation symbol to identical portion of fault tree

 Transfer In

 Transfer Out

Continuation symbol to similar (but not identical) portion of fault tree

 Transfer In

 Transfer Out

Figure 3 SYMBOLS USED IN FAULT TREE CONSTRUCTION

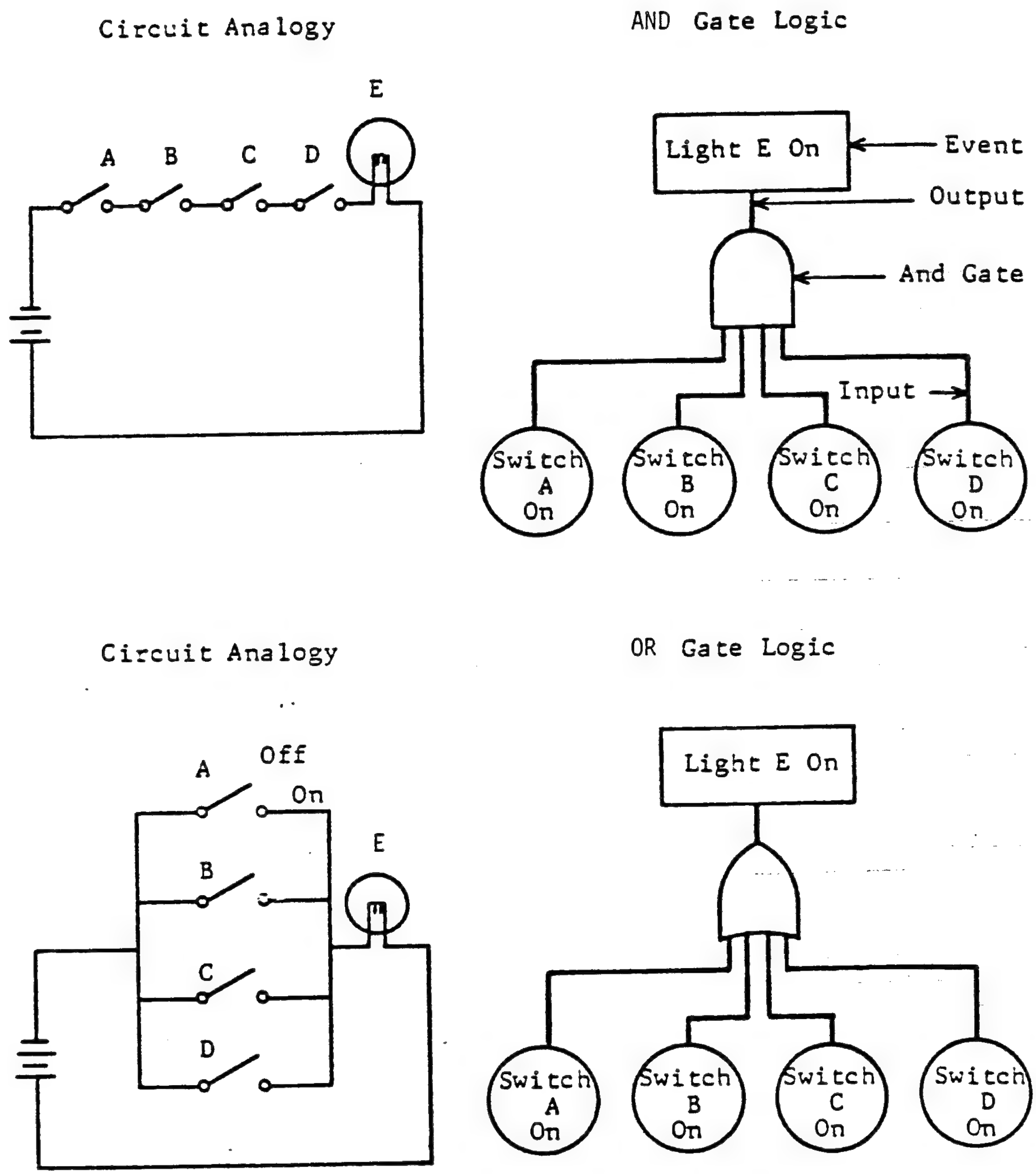


Figure 4 EXAMPLES OF USE OF AND AND OR GATES

3.3 QUANTIFICATION

IITRI has a fault tree analysis computer program for evaluating the fault tree diagrams. The first portion of the computer code uses a matrix approach known as the Boolean Indiated Cut Set (BIC) method to reduce the tree logic to a list of scenarios (cut sets) that "lead to" the undesired top event of the tree. These cut sets are the hazard scenarios that must be evaluated.

Each basic event on the fault tree must be provided a probability of occurrence or a failure frequency (with associated downtime) for quantification of the tree. Four types of data must be compiled to quantify the trees:

1. System Scheduling Data
2. Part Reliabilities
3. Human Error Probabilities
4. Initiation Probabilities

Scheduling information was largely inferred from the Batelle Report (reference 4). Part reliability data has been compiled at IITRI during prior hazards and reliability analyses from numerous sources. The primary source of reliability data used, however, was a compilation of non-electronic parts data developed by the Reliability Analysis Center, an IITRI organization in Rome, New York (Reference 5). Human error data has been compiled under a recent project conducted by IITRI for the Chicago Transit Authority (Reference 6) and that was the primary source for human error probabilities used. For initiation probabilities, the primary source of data was the Hercules Hazards Analyses for WADF presented in the Batelle report (Reference 4). The most sensitive material for which data was available was used for each stimulus type. HBX-1 data was adopted for many of the explosive cases studied. In addition, there were numerous cases where data was unavailable and subjective judgements had to be used. For example, the probability that a significant amount of explosive would remain is a vessel during maintenance operations or that a local initiation would propagate into the bulk of material present were not easily quantified. Therefore, judgements had to be used to establish probability values for the analysis.

The criteria for safety adequacy is stated in the contract as:

"The minimum acceptable level of risk for the operation and maintenance for the entire WADF complex and any subsystem is 97.5 percent probability with a 95 percent confidence level that a category 1 or 2* accident will not happen during 25 years of operation (40 hours per week)."

This translates to specifying that the hazard incident probability per year for the entire facility is less than or equal to 1/1000 with a 95 percent confidence level. The 95 percent confidence level criteria has been evaluated for the facility using the dominant cut sets derived for the different plant sections as a basis. These results are discussed in the next section.

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* Hazard categories are defined as follows:

Category 1 - Catastrophic. May cause death or system loss. System loss shall be defined as damage which results in the loss of 25 percent or more production capability and requires 30 days or more to repair.

Category 2 - Critical. May cause severe injury, severe occupational illness or major system damage. Major system damage shall be defined as that which results in more than 10 percent loss of production capability and requires more than 3 days to repair.

Category 3 - Marginal. May cause minor injury, occupational illness or minor system damage. Minor system damage shall be defined as that which results in 10 percent or less loss of production capability or requires 3 days or less to repair.

Category 4 - Negligible. Will not result in injury, occupational illness or system damage.

4. FAULT TREE ANALYSIS RESULTS IN TERMS OF THE 95 PERCENT CONFIDENCE LEVEL

In the three priority reports for this program (ref. 1, 2, and 3) fault trees are presented for each plant section at WADF and quantified using mean probability values for the basic events. Recommendations have been developed on the basis of those results.

As required under the contract for this program, the probabilistic results of the fault tree analyses must also be evaluated in terms of the 95 percent confidence level. A "Monte Carlo" analysis was utilized for this purpose. This was accomplished by describing each basic event as a distribution of probabilities, rather than a discrete value as was done previously. Lognormal distributions were chosen to describe the basic components in all cases, since the lognormal distribution is a fairly realistic model for part failures, human errors, and initiation probabilities. A random number generator was then used to sample off of the basic component distributions. The component probabilities derived in this way were then combined using normal fault tree numerics to derive cut set and top event probabilities for a given trial. This procedure was repeated within the computer code 1200* times using revised random numbers for each component for each trial to develop cut set and top event probability distributions. The 50% (median) and 95% confidence levels were determined from the compiled distributions by computing the area under the curve up to where 50% and 95%, respectively, of the computed probabilities have occurred.

Monte Carlo analyses were accomplished only for the highest probability cut sets identified previously in ref. 1, 2, and 3 using mean values. Systems showing very low top event probabilities were omitted from the Monte Carlo analysis. For high probability systems, only the highest two orders of magnitudes cut sets were included, since the highest two orders of magnitude have been determined to dominate the results.

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* 1200 trials was sited in WASH 1400---(Ref. 7) as being the number required to obtain a fairly smooth top event distribution and for which additional trials give little additional accuracy.

It should be noted that the narrowness of a probability distribution is indicative of the "certainty" of the input values used. When a cut set has a high computed probability and a narrow distribution (e.g., the 95% confidence level is one order of magnitude above the median value or less), the results are reasonably certain and modifying the system or procedures is the appropriate corrective action. Conversely, if a high probability cut set has a wide distribution (e.g., 95% confidence level approaches two orders of magnitude above the median value or higher), this indicates that insufficient or inadequate data was available. The appropriate action in this case is to do additional testing or analyses to better solidify the quantitative inputs.

The computer output for the Monte Carlo analyses are presented in the Appendix to this report. The results are summarized in Table 1. The error factor shown in the table is simply the ratio of the probability at the 95% confidence level to the median (50%) value. As mentioned above, error factors on the order of 10 indicate a high degree of conficence, and modifications of the system or procedure should be accomplished in most of these cases. Very high error factors, e.g., approaching 100, indicate that further testing or analyses should be done to better quantify the results. The error factors derived in the Monte Carlo analysis ranged from 2 to 122, with most cases greater than 10. This was expected in that most of the high probability (dominant) scenarios had a high probability because of conservative assumptions that had to be made because of the uncertainties in the inputs.

The recommendations presented in the next section generally reflect the results of the Monte Carlo analyses. However, in some circumstances the results had to be tempered by practical considerations.

≤ 10 high confidence
>> 10 low confidence

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS

System	Typical Error Factor, or Range	Comments/Conclusions
Washout/Steamout		
• North Tower	10-34	Dominant Scenarios involve runaway reactions. Significant uncertainty is associated with the specific conditions at which runaway will be induced. Simulation tests are recommended.
• South Tower	15-61	The great majority of dominant scenarios involved equipment damage or (less frequently) initiation due to projectile impact. The large uncertainty here is due to the human error probabilities and the probability that damage or initiation will result from an impact.
	27	Prolonged Process Shutdown due to Yellow D "plateout" problems. The high error factor arises from uncertainty in the time required for settling to occur and the severity of "plateout" required for a prolonged hold.
Refining Building	10-34	Dominant Scenarios involve runaway reactions. Significant uncertainty is associated with the specific conditions at which runaway will be induced. Simulation tests are recommended.
Bulk Explosives Disposal Building	(not evaluated due to low probabilities derived using mean values)	
Process Water Treatment Facility	(not evaluated due to low probabilities derived using mean values)	
Preparation Building		
• Off-Loading And Distribution Areas	15-35	Item Impact Causing Equipment Damage or Initiation. The uncertainty is associated with the probabilities that equipment damage or initiation will occur given that impact occurs.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
• Cell 1	(not evaluated due to low probabilities derived using mean values)	
• Cells 3,4,5,6	12-23	Dominant scenarios involved equipment damage or initiation due to an item impacting equipment or being dropped (e.g., item dropped into drop tank over-filled with items, not adequately filled with water, or not positioned at drop location. Uncertainty in these scenarios is related to the criteria for significant damage or item impact initiation. Although item impact initiation tests appear to be indicated, too many trials would be necessary in this case and testing is considered to be impractical.* Therefore, protective measures, e.g., to assure that the drop tank is full of water, and not over full with items, are suggested.
Accumulator Building	5-7	Initiation due to tool dropped into Type III container while vacuum system is being emptied or due to forklift penetration into container or vessel. Procedural recommendations (tool tied to operator, area wetted, water in container, etc.) are pertinent here.
	26-38	Impact initiation during insertion of lids into propellant containers due to the wrench or lid being dropped onto the lip or due to rough handling of the tool. The high uncertainty here is attributable to defining the probability that the lip is contaminated at the impact location and determining whether the reaction would propagate to inside the container. Procedural precautions are suggested.
	12	Impingement initiation caused by a pinch valve rubber boot leak. Uncertainty is attributable to not having data for the reliability of the rubber boot. Better reliability data would be helpful in this regard.

* Conversely, since the DOD has such a large amount of items to be disposed of, such testing may not be impractical, at least in terms of the cost of the test materials.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
	16-28	Impact Initiation during maintenance due to a dropped tool or rough handling of the tool. Uncertainty is attributable to the probability that the ignition source is at the propellant and for how often emergency maintenance will be required.
	16	Initiation due to a propellant container being dropped during jib crane maneuvers. The uncertainty here is in defining the container impact initiation probability. The very large number of trials that would be required makes testing impractical in this case.
	48	ESD initiation due to operator wearing ungrounded shoes. Uncertainty is due to the reaction propagation probability combined with human error probabilities.
Mechanical Removal Building		
• Cell #1	15-17	The dominant scenarios involved impact initiation of primer tubes. Uncertainty is due to initiation probability; therefore, testing is recommended. The large number of trials required may make testing impractical here also.
• Cell #2	11-26	The dominant scenarios involved intiation of a MK4 charge head as it falls (sawn off) into the collection tray or as it is thrown onto the floor after sawing. The major uncertainty is related to the likely impact location. In this case, the extremely high probability of the event indicates redesign of the fixture to prevent release of the sawn off head.
	11	ESD initiation of a sectioned item due to the plastic sheet used to cover the item. Recommend use of conductive plastic.

TABLE 1. SUMMARY OF RESULTS OF
MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
	12-19	Several scenarios concerned initiation of an item during sawing due to binding of the saw blade or thermal initiation during normal sawing. Uncertainty is related to whether operating conditions (force, cutting speed, or misalignment) will cause initiation. Recommend that "safe" conditions be identified for all items to be cut and strict controls be enforced to assure that the proper settings are used.
	16	Initiation due to a tool being dropped onto contamination during servicing of the filter media. The major uncertainty is whether the resultant fire would propagate back to the filter and involve a significant amount of material.
	19	Initiation due to a forklift prong penetrating an item. The major uncertainty is associated with whether the prong will penetrate the item or merely push it aside.
• Cell #3	17, 19	The dominant scenarios for Cell 3 involved initiation of contamination on the carriage/rollers during loading of items and initiation due to forklift prong penetration into an item. The uncertainty was due to difficulty in defining whether the reaction will propagate to involve a large quantity of material.
	14-26	ESD initiation due to ungrounded shoes worn by an operator. The uncertainty in this scenario is attributable to defining the probability that the spark will occur at contamination present.
	15	Item dropped during jib crane maneuver causing initiation. The uncertainty is due to defining the item impact initiation probability.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
Large Cell B	13	The highest probability scenario involved ESD initiation from the plastic sheet used to cover the sectioned items. The major uncertainty is the spark energy. It is recommended that conductive plastic, or equivalent, be used.
	20	This scenario involves initiation due to a sectioned item falling onto the exposed end when it is knocked off a DLT cart by a forklift. The major uncertainty is the probability that the item will fall onto the exposed end.
	10, 17	Initiation due to a forklift prong impacting/penetrating a sectioned item. The major uncertainty is whether the prong will penetrate or merely shove the item aside.
	14-17	Equipment damage due to an item being moved into equipment during bridge crane or forklift maneuvers. The major uncertainty is the probability that the equipment will be damaged significantly by such an impact.
	7	Initiation due to a tool being dropped onto contamination while the filter media is serviced. There were no major uncertainties. Recommend controls to prevent impact initiated by dropped tool, e.g., tool connected by a cord to the arm and keeping the area wet.
	17-118	Initiation during cutting due to misaligned saw blade, due to thermal initiation during normal sawing, or due to incorrect force/speed setting. Large uncertainty due to not knowing conditions at which initiation will occur. Recommend study to determine these conditions for all items to be processed and controls to assure that the proper conditions are applied.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
Large Cell C	13-19	The majority of the dominant scenarios in Large Cell C involved initiating of an item or fuze by impact. The primary source of uncertainty in these scenarios is due to the item impact initiation probability. Although testing to determine this value is indicated, the extremely large number of trials makes that recommendation impractical.
Decontamination Building		
• Lead Items Furnace	(not evaluated due to low probabilities derived using mean values)	
• Detonating Items Furnace	45-64	The only dominant scenarios for the detonating items furnace involves items continuing to detonate upon exiting the furnace due to latent heat. The major uncertainty in this scenario is in part due to defining the probability that major system damage will occur as a result.
• Tray Type Furnace	32, 122	Explosion in furnace due to full or partially full items being processed. The high uncertainty is due to difficulty in determining the frequency that full or partially full items will be routed to the Decontamination Building. Procedural and DLT System Controls to prevent this are suggested.
	10, 14	Fire in Bag House due to recuperator heat transfer degradation. The uncertainty is attributable to defining the frequency of duct blockage and heat transfer surface degradation.
	5	Equipment damage due to the building crane dropping a heavy item. General recommendations related to training, licensing, and certifying of personnel are pertinent here.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
Large Items Flashing Chamber	24, 27	Operator becomes charged due to ungrounded concrete pad outside of building and ESD ignites contamination in item. Uncertainty is attributable to whether or not significant charging actually will occur. It is recommended to keep the pad wetted down to assure that the concrete maintains a reasonably high electrical conductivity.
	21	Impact initiation of contamination on mine car as an operator is raking out the sand bed. The major uncertainty in this scenario is in defining how likely it is that the rake can impact metal at the bottom of the car at the location of contamination present.
	9-20	Operator is injured by not getting away fast enough while using non-electrical ignition of a powder train to start flashing. In this case, it is simply recommended to use remote electrical ignition of the smokeless powder instead.
	7-17	Impact initiation of an item or smokeless powder container due to it being dumped off of a DLT cart, dropped by a jib crane, forklift impact, items not properly braced on a mine car, etc. Some uncertainty in defining the initiation probability accounts for the wide distributions for these scenarios.
	38	Chamber explosion due to too much propellant packed into the item to be processed. The required human errors account for the high uncertainty in this scenario. Rigid management controls should be enforced.
	2	Train collision while positioning or removing gondolas. This is a single failure rate derived from railroad statistics.

TABLE 1. SUMMARY OF RESULTS OF MONTE CARLO ANALYSIS (cont.)

System	Typical Error Factor, or Range	Comments/Conclusions
Driverless Tractor System, Off-Loading, Dock, and Magazines	32	The only dominant unique scenario in this fault tree is that of an item falling out of a box car onto an operator at the unloading dock due to the load having shifted during transport. The uncertainty in this scenario is attributable to the estimate of how often a load will have shifted during transport such that it will fall onto the operator when the box car door is opened. Extreme care should be exercised by operators unloading box cars because of this possibility. Use of a come-along is recommended.

5. CONCLUSIONS AND RECOMMENDATIONS

In this section, the conclusions and recommendations presented in the three Priority Reports are consolidated. Additional suggestions, in the category of "good practices" are also included, although not all of these emerged directly from the hazards analysis. The recommendations and conclusions have been prioritized using descriptive terms such as (in decreasing order of urgency) "strongly recommended", "recommended", "suggested/good practice", and "concluded". General recommendations that apply to more than one area are presented separately at the end of the section.

North Tower and Refining Building

- It is strongly recommended that a comprehensive experimental program be conducted to evaluate the potential for thermal explosion in liquid explosive holding vessels with realistic contaminants and aged materials. The validity of small scale tests for obtaining parameters such as pre-exponential factor and activation energy should be investigated by conducting several large scale simulation tests, with and without agitation. Localized effects of a contaminant should be considered since they may really dominate incidents of this type. It is expected that tests of the type conducted at China Lake (e.g. Ref. 8) or in Holland (Ref. 9) with additional explosives and contaminants, and a wider range of conditions will serve well to better map out problem areas.

- The options available for protecting against thermal explosion at WADF should be evaluated further to select the best approach balancing the effectiveness of the approach with the costs required for modification of equipment. The existing system is not expected to provide much protection in the event of a runaway reaction. The options warranting evaluation include use of an under-surface deluge with swirl and enhanced agitation.

- The valves in the drain lines beneath the melt kettles and separator should be moved as close as possible to the vessel to eliminate the dead space in the pipes.

- In order to better sense the onset of a runaway reaction the use of numerous thermocouples at a variety of locations inside the vessel should be considered. The onset of runaway will probably be localized and a single thermocouple is not likely to be at the right place. The more locations that are kept under observation, the better the chance is that the event will be sensed early.

- In the event of a runaway reaction, dumping the contents of the vessel to pans using the existing system should be accomplished if no better alternative exists. Operators should be made aware that the dump may not be fast enough, and they should evacuate the area quickly.

- Use of plastic tipped lances for steamout in the North Tower should be considered. A plastic tip would reduce the chance for impact initiation during steamout, but the potential for ESD should be evaluated before making such a change.

- Similarly, use of a plastic coated dipstick in the separator should be considered. In addition, a procedure or device should be developed to assure the dipstick is cleaned off prior to reentry into the vessel.

- During major maintenance involving removal of melt kettle or separator covers, extreme care should be taken to assure that the impeller will not contact the vessel wall during operation. This can be accomplished by incorporating several independent inspections of the equipment prior to operation as part of the overall maintenance procedure.

- The screen in the line leading into the North Tower separator vessel should be checked periodically for structural integrity. As long as that screen is in good condition, foreign parts or large pieces of contaminant cannot enter the equipment below during normal operation. The possibility still exists that something will be left behind after maintenance actions, however.

- The credibility should be evaluated for the scenario mentioned in the previous section in which a piece of solid explosive forms in a low point in the drain base between the tilt table to the separator vessel and breaks loose impacting the grate above the separator. The velocity achieved by the piece and the potential for initiation are uncertain. Simulation tests are suggested to better evaluate this potential hazard.

- It is suggested that a vacuum trap be put in the lines between the melt kettle and the vacuum pump. This will essentially eliminate the possibility of liquid explosive getting into the pump.

- Prior to major maintenance on vessels in the facility, the vessels should be thoroughly drained and steamed out. Even if a film of explosive remains in the vessel, the potential exists for the film to "flash" and injure the maintenance personnel present.

- Similarly, throughout the North Tower and Refining Building, the piping and ledges present are a maze of collection points for explosive dust layers to develop. Cleanup is quite difficult. The major potential hazards are "flash" reactions that could

injure personnel, as well as a possible "train" for the reaction to get to a larger quantity of material, elsewhere in the building, e.g. an open item. The best solution to this problem is frequent hose-down of all the equipment, piping, ledges, etc.

- Insulation on steam lines within these buildings could pose a contamination problem. If a crack develops in the shell and explosive dust builds up, a fire could eventually develop. Frequent inspections should be made of the insulation's condition.

Rotoclone Cleaners and Duct Work

- Air handling ducts should be inspected and cleaned frequently to avoid any significant buildup of an explosive dust layer inside the ducts.

- The Rotoclone should be tested frequently to assure efficient operation. The inside walls of equipment and ducts downstream of the scrubber should be inspected to assure that a dust/residue layer is not developing.

South Tower

- Yellow D solubility in water is extremely sensitive to temperature. This results in a real potential for plateout of yellow D within the south tower equipment requiring hazardous cleanup. Therefore, it is suggested that alternate methods of treating Yellow D be considered.

- Yellow D is an extremely toxic material. Great care must be exercised to protect operators from becoming exposed to this material. It should also be recognized that A-3 being processed in the South Tower can become contaminated with Yellow D if equipment is not thoroughly cleaned between operations. Personnel handling the A-3 may then be exposed to Yellow D without knowing it.

- Transport of Yellow D to the bulk incinerator is of concern. The transport containers apparently have been designed such that the temperature will remain sufficiently high during transport to avoid plate out. If an unanticipated delay occurs in transit (this is not that unlikely) Yellow D could plate out within the vessel. Redissolving the Yellow D before dumping the contents into the slurry tank at the bulk incinerator is likely to be a hazardous operation.

- The structural integrity of the floor grating within the South Tower should be evaluated to assure that the heavy items that are to be handled will not fall through the grating if an item is set down on the fourth level.

Bulk Explosives Disposal Building

- Assure that the hydraulic fluid being used has been evaluated for compatibility with the explosives and propellants to be processed - this really should be done for the total plant. On the ground level cement floor it is quite likely that some hydraulic fluid could be mixed with explosive residue.

- A compatibility library should be set up at the WADF. Any time new combinations of materials will come in contact, the library should be consulted. For combinations for which no data exists, a laboratory should be set up to run the required compatibility tests.

- Tests should be conducted to simulate large chunks of explosive being put into the grinder. It should be determined whether such large pieces will ignite by impact in the grinder with and without water present. The consequence of such a reaction is also of concern - i.e. will the result be "fire cracker" type explosions or a more massive event with propagation between pieces of material? It is anticipated that the "fire cracker" type event will occur and possibly could damage the equipment.

- Although great care is taken to prevent steel drums containing waste material from impacting each other in the bulk explosives disposal building, it is possible that drums can impact each other while stacked more closely enroute to the building. Care should be taken to assure the outsides of the drums are clean prior to transport and that the drums somehow be spaced on the cart.

- It is suggested that a side chute and automatic gate be incorporated at the metal detector on the conveyor feeding the grinder. If metal is detected in the present arrangement it appears that it still could be carried into the grinder by residual water flow. A side chute with a gate would serve to prevent metal from getting into the grinder.

- When changing the grinder blades, the grinder wheel should not be rested on the floor grating, unless the structural integrity of the grating has first been evaluated to assure that the grinder will not fall through.

- Experience shows that explosive contaminants can be expected beneath the grinder blades, and on the screw threads. The grinder should therefore be decontaminated before going to the maintenance shop for blade replacement, in order to protect maintenance personnel from initiation hazards. Long duration heat decontamination would be desireable from the safety standpoint but should be evaluated first to assure that warping of parts or altered heat treat would not result. An acceptable alternative may be keeping the grinder wet with a compatible wetting agent during disassembly.

Process Water Treatment Plant

- It is recommended that tests be conducted to determine the catalytic effects, if any, of anthracite coal on the decomposition of explosives and mixtures of explosives present in the process water treatment plant.

- It is normal practice in propellant and explosives facilities to use nonmetal shovels instead of metal ones. It is assumed that this will also be the case at WADF. The hazards analysis indicated that metal shovels could initiate material in the sumps at the process water treatment facility. The resultant reaction could injure personnel present, at a minimum. Therefore, the use of non-metal shovels is strongly recommended.

- At Hawthorne, the process water treatment plant situation is different from that at even other explosives plants. At Hawthorne, mixtures of a wide variety of propellants and explosives must be processed - not just a single material. As long as water is present in large quantities there should not be a problem. However, if water is drained from components and materials are allowed to dry during a shutdown, dry mixtures of energetic materials of unknown characteristics will be present. It is, therefore, recommended that components be kept flooded during such shutdowns.

PREPARATION BUILDING

- It is recommended that cartridge cases to be processed in the preparation building be tested to determine if a flammable mixture of volatile vapors with air is present in the void spaces in the case. Naturally, this is only relevant for cases containing propellant that was manufactured by a solvent process. Analyses conducted in this study indicated that a flammable mixture may be present, but there were significant uncertainities in the analyses to determine this for sure. Therefore, an experimental solution is warranted. A gas sample can be extracted from a closed cartridge case by drilling a small hole into the case, or a flammable gas detector can be used to monitor the gas while cases are opened. In both tests precautions must be exercised to prevent and guard against an ignition of the gases or propellant in the case. If uncertainty remains even after such testing, it is recommended that a flammable gas detector be installed in the vicinity of the case cutter and pull apart machines to warn operators of the presence of a flammable gas during the operation of Cell 5.

- It is imperative that a water cushion be present at all times for fuzes dropped into the "fuze drop" tanks in Cells 3 and 6. It is possible that the operators will allow this tank to become empty (no water) or to become overfilled with fuzes.

In either case, a finite probability exists for initiation of the fuzes by impact. Therefore, it is recommended that a sensor be installed to warn the operators of insufficient water at the start of an operation and of too many fuzes during the operation. This could be accomplished by sensing the weight of the tank. Prior to operation, the weight must be at least that of a water filled container or the operation cannot begin by interlock. During operation, if the weight exceeds the level at which fuzes are no longer protected by a significant layer of water, a warning should be actuated. Alternate solutions to this problem should be evaluated.

- Preparation Building, Cell 1, is now earmarked for storage of "unsafe" items ... until enough of them accumulate to be taken to the disposal site". This is a blatantly unsafe practice and it is recommended that it not be done. Should an "unsafe" or "suspect" round or item be detected, its disposal--or at the very least, its removal from a busy operating building--should be immediate, and under strict control. To do any less than this would be a highly unsafe act. Removal, after all, should pose no major hardship. Based on the combined assumed throughput rates of cell 3, and cells 4-5-6, and the 1 per 1000 "suspect" item incidence projected, we're only talking about 3 per day.

- It is anticipated that the robot manipulators will require frequent preventive maintenance to minimize the possibility of mechanical or control failures that can result in impacts causing equipment damage and/or initiation of munitions items being handled.

- It is recommended that partitions be constructed to better isolate the different individual work stations in the Preparation Building corridor, receiving area, and distribution area. Currently, if an incident occurs which causes a round or item to fire or detonate, personnel at other work stations are in a direct path for serious injury by blast, fragments or an accidentally launched projectile. Isolating personnel to the extent practical with partitions will at least increase their protection against fragments and projectiles.

- For the various unscrewing operations in the Preparation Building and elsewhere, it is suggested that consideration be given to spraying the threaded areas with a compatible penetrating lubricant before attempting to unscrew the parts. This could improve the safety of the operation by wetting any trace contaminants which may be present, and by minimizing the force required to loosen the stuck threads.

ACCUMULATOR SYSTEM

- It is recommended that the rubber boots inside the pinch valves in the accumulator building be periodically inspected for wear that could lead to a major leak. The rubber boots or pinch valves should be repaired or replaced if such wear is observed. A large leak in the rubber boot could cause impingement initiation of small propellant grains being processed.

- Bearing failure in the smokeless powder conveyor can result in a fire due to frictional heating at a stuck roller or due to a bearing overheating. It is recommended that the roller bearings in the smokeless powder conveyor be inspected and maintained frequently. A conservative inspection/maintenance and part replacement schedule should be established based on the manufacturers reliability data for the bearings in use. With regard to overheated bearings, periodic infrared photographs during the operation or strategically placed infrared sensor might be useful to sense the onset of the bearing failure.

- Care should be taken during the setup of the rubber receiving hopper to assure that it does not push too tightly against the moving conveyor belt. Calculations indicated that a nominal force (10 lb) could result in a significant temperature rise at the interface.

- Whenever a powder or granular material is emptied from one vessel or hopper into another container, the possibility exists that a significant voltage difference will develop between the two containers due to electrostatic charging. If the voltage difference is high enough, a discharge can occur between the containers or to another object, for example to an operator. Such a discharge could ignite the material being transferred. Therefore, it is strongly recommended that positive electrical bonding be assured between the weigh hopper and the Type III or MKIV container being filled in the accumulator system, as well as between the various dust collector and vacuum system hoppers and the Type III container used during system emptying operations. A reasonable assurance of bonding can be achieved by placing the Type III or MKIV container onto a conductive rubber covered metal platform (or the roller conveyor in the case of the filling operation) that is permanently bonded to the equipment item being emptied. The platform must be kept clean or its effectiveness will be lost. In addition, a separate bonding strap should be manually connected between the hopper being emptied and the container being filled. This redundancy affords some degree of assurance that bonding will be achieved only as long as the electrical contacts are clean and secure.

- The dust collector and vacuum system ducts should be inspected and cleaned frequently to avoid any significant buildup of a propellant dust layer inside the ducts. Periodically flushing out (e.g. with hot water) should be considered to minimize the buildup. Materials handled by the dust collector and vacuum systems should be checked to assure compatability at the temperatures to which they will be exposed inside the ducts.

- Preparation Building, Cell 5, and the Accumulator Building, together, present a unique problem, viz., segregation and control of "dissimilar" propellants. Propellants dumped in Cell 5, are to be conveyed to the Accumulator Building for packaging"...for storage or for sale". Care must be taken in both locations, therefore, to prevent uncontrolled mixing of different propellant types. Each propellant formulation must be separately and individually packaged because mixing -- although not hazardous per se--would pose a serious problem or threat to a buyer, in the event of sale. Processing methods for reclamation or reuse of double- or triple-base propellants (e.g., M26 or M30) are much different than those for single-base (e.g., M1, M6, or BS-NACO). To mix them together would cause an intolerable, and potentially hazardous, problem in certain cases. For example, introduction of NG into a process designed to recover NC from single-base propellants would create a real safety hazard.

MECHANICAL REMOVAL BUILDING

The analyses of the mechanical removal building included the punch press operation (Cell 1), the small band saw operation (Cell 2), and the hole sawing operation (Cell 3).

Punch Press Operation (Cell 1)

The hazards analysis of the punch press operation was based on the assumption that long primer tubes will be segmented in Cell 1. If primer tubes are to be processed in Cell 1, the following recommendations are provided:

- It is recommended that drop tests be carried out on primer tubes in order to accurately determine their response to this stimulus. Should such tests show a significant probability of initiation, it is strongly recommended that additional tests be carried out to determine the response of primer tubes enclosed in a Type II container to impact, and to test various methods of cushioning within the container to prevent such initiations.

- It is strongly recommended that primer tubes be instrumented and subjected to the shearing operation to determine functional forces which arise during the shearing operation. Small amounts of black powder may be included in these tests to determine characteristic response data.

- These tests should be done prior to the startup of the Cell 1 operation. If initiation is likely, the extent of damage to the cell due to an individual primer tube being ignited and due to a Type II container filled with primer tubes being initiated should be evaluated based on simulation testing. It is conceiveable that the consequence of an initiation, e.g. during shearing, can be tolerated in this case.

Small Band Saw Operation (Cell 2)

- The small and large band saw operations are quite similar in many respects. Therefore, many of the recommendations made for the large band saw apply here also (see Section 4.4.2)

- In the small band saw operation, the "head" of the item will either fall into a tray, or be thrown after sawing is completed. In either case, the initiation of a significant amount of explosive in the head (about one pound) is expected. Sympathetic detonation of the three depth charges in the fixture could also occur, resulting in major system damage. It is strongly recommended that the fixture and carrier plate be redesigned so that the "head" of the item is secured and does not fall freely after sawing.

Hole Sawing Operations (Cell 3)

- It is strongly recommended that a conservative inspection and replacement schedule be developed for the cutters to be used in Cell 3. It is expected that these cutters will generally have a short life span and will require frequent replacement. A dull or broken cutter can result in initiation inside a munitions item being processed in the cell.

- It is strongly recommended that operating parameters be derived for the hole sawing operation, such as was accomplished for band saws and hacksaws in reference 4. It is expected that criteria for teeth per inch, cutting force and cutting speed must be carefully defined for each item to be processed to minimize the probability of initiation during cutting.

- It should be noted that the most hazardous condition during hole sawing will be cases where the hole is not positioned correctly and loose internal plumbing is sawed into (by analogy with the band saw results presented in reference 4). In these cases, increased frictional heating occurs due to cocking of the loose internal part, while exposure to coolant is restricted. In addition, relatively large quantities of explosive could remain hidden behind the internal plumbing and become ignited.

LARGE CELLS

The two active operations in the Large Cell area were analyzed for potential hazards. These were the unscrew machine (Cell C), and the large band saw (Cell B). Cell A is presently empty and did not require a hazards analysis.

Unscrew Machine (Cell C)

- The manual removal of the base fuze and associated cleaning of the base plate and fuze are considered to be inherently hazardous operations. If the item is struck or scraped with the wrong type of tool, fuze initiation may result. In addition, the items are filled with highly toxic yellow D, and the operator could be exposed to this chemical. It is recommended that alternate solutions to this problem be evaluated.

Large Band Saw (Cell B)

- It is strongly recommended that an untreated nonconductive plastic sheet not be used to cover items sectioned at Cell B. Rather, the sectioned items should be covered with a relatively high conductivity, low permittivity material, for example conductive plastic, paper or treated cloth. Otherwise, an electrostatic discharge from the plastic sheet has a finite probability to initiate the exposed explosive.

- The sawing operation is inherently hazardous. Strict management controls must be enforced to insure that the proper force and saw cutting speed are used for the particular item to be cut. If a contaminated empty item is to be sawed, the initiation probability can be significantly higher than for a full item (from reference 4 analysis) and the sawing conditions must be adjusted to account for this. While sawing contaminated empty items internal plumbing should be avoided, because this is where thermal initiation is most likely.

ROTARY FURNACES IN THE DECONTAMINATION BUILDING

- By far the majority of problem areas that were identified will result in lost production and not a major hazard.

- The potential hazard with by far the greatest consequence is that of the truck driver hitting the nearby unprotected propane tank while moving the scrap metal recovery trailer. It is recommended that strategically located posts similar to those protecting the lightning poles be positioned around the propane tank. Proper placement of such posts would still allow easy access for filling the tank. An alternate approach would be to relocate the propane tank.

TRAY TYPE FLASHING FURNACE IN THE DECONTAMINATION BUILDING

- Strict controls must be enforced to assure that inspection procedures are accomplished with care so that filled or partially filled items are not put into the tray type furnace.

- It is recommended that a deluge system be installed in the baghouses at the Decontamination Building.

LARGE ITEMS FLASHING CHAMBER

- It is strongly recommended that detailed inspections be carried out on decontaminated items processed in the Flashing Chamber. The items should be disassembled and or sectioned so that bolt threads and other tight areas can be observed to assure that contamination does not remain after flashing is completed. Since "flashing" is a short duration high temperature exposure it is quite likely that the heat will not have time to penetrate to all of the interior contaminated regions of an item. This type of inspection procedure should be accomplished until a reasonable data base has been developed to assure that decontamination by flashing does indeed work and is reliable.

  It should be noted that visual inspection of a treated item will not necessarily assure adequacy of decontamination. Cracks, threaded areas, and sub-surface cavities or flaws can still house hidden and undetectable explosive material.

- Raking of the sand beds on the mine cars should be carried out with care for each flashing cycle to assure that very little contamination remains in the sand and that a cushion is present to prevent direct metal - metal contact. It is recommended that non-metal rakes be used for this purpose to minimize the possibility of impact initiation of contamination that remains on the mine car.

- It is recommended that the concrete pad outside the flashing chamber be periodically wetted down to minimize the possibility of electrostatic discharge from operators or equipment as contaminated items are handled in this area.

- It is strongly recommended that remote purely electrical ignitors be used to initiate the burns in the Flashing Chamber. Squibs or other ignitors that contain explosives that are sensitive to ESD are undesirable because of the potential for premature initiation. Use of a powder train is undesireable due to the possibility that the operator could inadvertantly light the powder train too close to the items, or not set up a long enough powder train, or become injured on his way out and not be able to escape in time.

- It is recommended that reliable non-combustible bracings be designed for each type of item to be decontaminated in the Flashing Chamber. "Make-shift" arrangements should not be used because of the high potential for the bracing to collapse and items to fall. The smokeless powder and/or contamination could become ignited from the impact in such an event.

- It is recommended that operators at the Flashing Chamber be trained to know what all possible smokeless powders to be used will look like. Any material that does not fit this pattern should not be used in any event. For example, flakes, chips, or small pieces, etc. could be explosive misrouted and actually intended for processing in the Bulk Incinerator. Packing items on a flashing car with such a material could result in a major explosion inside the chamber.

- It is recommended that criteria be carefully defined to limit the amount of propellant packed into items of different types and as a function of the ventilation holes available. Too much propellant could result in an explosion if the material is confined too strongly. These criteria should be based on tests. Test data may be available to help develop such criteria. Different smokeless powders are likely to require different criteria.

- Strict management controls should be enforced so that items are carefully inspected to assure that a total of less than 10 pounds of explosive is in all the items prior to flashing. An explosion involving an equivalent of more than 10 pounds of TNT could seriously damage the chamber. This probably requires that the 10 pounds be in one location rather than divided among the items to be processed, but a total of 10 pounds must be avoided.

- Control of the key to actuate the ignition system from the remote control location should be assigned to one specific individual in the operating crew. No one else should be permitted to actuate the firing circuit. The key control operator should be responsible for final inspection of the furnace before closing the doors, to assure that all other personnel have been evacuated to the remote control location. It is recommended that the accountability, for all personnel prior to and during the flashing operation be assigned by procedure to one specific individual.

- Under the Burning Ground requirements of AMC regulation 385-100, it is required that a 24 hour period elapse between "burns" on a single pad. This is to insure that no "hot-spots" are present on the pad when the next charge is distributed, to protect personnel from premature ignitions. Since the sand-bed concept in the flashing furnace is analagous to a burning ground pad, the same safety precaution should logically apply. It is suggested that Army Safety personnel review the operation of this unit versus the Burning Ground safety requirements, and assure that all applicable safety rules are operationally incorporated.

DRIVERLESS TRACTOR SYSTEM, OFFLOADING DOCK, AND MAGAZINES

- When the DLT is operated in the manual mode, it is recommended that the first trailer behind the tractor be used as an empty spacer, to protect the operator from lethal heat in the event the load accidentally ignites.

- It is recommended that driverless tractor loads be positioned with the lowest possible center of mass. This will minimize the chance for the load falling off of the carts in the event of a fast stop.

- The driverless tractor system that has been installed at WADF is rated as EE type equipment, rather than EX as was required in the specifications for the DLT. According to AMCR 385-100 these two classifications for battery powered equipment can be used as follows:

  "Type EX equipment is approved for use in Class 1 Group D and Class II Group G hazardous locations." "Equipment used in atmospheres containing explosives dusts, flammable vapors or flammable gases, must meet requirements for EX industrial trucks."

  "Type EE industrial trucks are satisfactory for handling all classes of ammunition and explosives packed in accordance with Department of Transportation Regulations. Type EE industrial trucks may be used for handling partially loaded ammunition in corridors or ramps connecting hazardous operations, provided the ramps and corridors are not Class I or Class II hazardous locations as defined in paragraph 6-3f. Type EE equipment shall not be used in Class I or Class II hazardous locations."

  Use of type EE equipment in some buildings at WADF appears to be borderline at best. The DLT should not be used in any areas where explosive dust or flammable vapors may be present.

- The highest probability scenario in the DLT/Offloading Dock/Magazine category was that of items/containers falling out of a railroad boxcar onto an operator when the boxcar door is opened. This could happen if the load is not properly tied down and shifts during transit. Great care should be exercised by the operators to carefully open the boxcar doors to assure that the load is not in a tenuous position. To guard against operator injury from falling loads resulting from shifted cargo, it is recommended that a come-along should be used to open box-car doors. The operator, then is more likely to be removed from the door opening area.

AIR BLAST PROTECTION FROM AN EXPLOSION IN A CELL

The adequacy of protection from airblast was evaluated under this project and is discussed in the Priority 3 Report. Conclusions of that study are repeated here:

- Pressures transmitted to the corridor due to the "piston action" of a cell door were determined to be reasonably low, but on the order of the 2.3 psig criteria for safety adequacy.

- Pressures transmitted to the corridor due to leakage around the edges of the cell door were determined to be quite high in many cases, and up to about 30 psig in one instance. Therefore, it is expected that unacceptably high pressures are possible locally close to the cell doors in the event of the explosion of a maximum or nominal quantity of explosive detonating in several of the cells.

- At the mechanical room for the Bulk Incinerator Building, a ventilation duct provides a fairly direct route for airblast to channel into the mechanical room. Calculations showed that the average pressure in the mechanical room would be quite low, but locally at the entrance to the duct the pressures could exceed the 2.3 psi criteria significantly if a maximum sized explosion occurs in the process area of the Bulk Incinerator Building. Because the traffic flow pattern for personnel in the control room/mechanical room is likely to have personnel in the vicinity of the ducts, a severe injury could occur in the event of an explosion. It should be noted that the probabilistic analysis indicated that such an explosion would be quite unlikely, and the low probability should be considered in deciding whether corrective action is warranted in this case.

GENERAL RECOMMENDATIONS FOR THE WADF FACILITY AS A WHOLE

- Every operation on every equipment item must be covered by a written procedure, reviewed and approved by operating and safety management personnel.

- A comprehensive training program should be required for all plant personnel, including information on potential hazards.

- All equipment operators should be given appropriate training courses and certified or licensed for operations in which they will be involved.

- All plant personnel should be tested for electrical grounding of foot gear at least once a day with a sign-in sheet.

- Frequent cleanup of each plant area is mandatory to prevent buildup of contamination. Such cleanups should be scheduled as part of the operating procedures for each area.

- Area surfaces should be kept wet during maintenance as part of the procedure. the equipment should be thoroughly cleaned/ decontaminated prior to any maintenance operation.

- It is recommended that a 2 locker system be adopted for plant personnel. One locker should be for street clothes and a second locker for work clothes. All clothing should be changed at the beginning and end of the shift. Clothing should be supplied by the plant - nothing taken home. A shower should be taken enroute from taking off work clothes to putting on street clothes. This procedure will also help avoid street shoes being mistakenly worn in the plant areas.

- An area entry and hot work permit program should be set up to assure that all temporary repairs and maintenance operations are well thought out and accomplished with several levels of safety and management checks.

- During maintenance, tools should be connected to the workmen by a cord wherever practical to help break the fall of the tool if it is dropped.

- Strict cleanliness must be enforced at all times in the plant, particularly when personnel leave contaminated areas to go to lunch or at the end of the shift. Nothing should be eaten in the work area. No food should be allowed in the work area.

- A medical surveillance program should be set up to screen personnel for specific jobs at hiring and to assure that long term health damage is avoided.

- Any major system modifications made in the future should be safety analyzed upon completion of their design.

- It is recommended that a compatibility data library be set up at WADF. Whenever a new material is to be handled anywhere at the site the existing data should be searched for potential problems. If the existing data base is insufficient to evaluate the new material, a battery of compatibility tests should be run on the material.

- Existing calculation methods for estimating the electrostatic discharge energy produced by a charged dielectric surface generally overestimate the spark energy in this type of ESD scenario. The actual spark energy cannot be calculated using

such methods. IITRI has developed a simple model for estimating this spark energy from a dielectric surface. The model lacks the required input parameter values and validation. It is suggested that tests be conducted to provide these inputs and to validate the model. This will provide a much improved quantitative analysis method for ESD hazards associated with dielectric surfaces.

6. PRIORITIZING THE RECOMMENDATIONS

The recommendations presented in Section 5 are all considered to be significant and should be evaluated carefully by ARRCOM personnel. To help ARRCOM personnel decide which recommendations should be pursued first, Table 2 has been developed. The recommendations are listed in the order that they appeared in Section 5 of this report. For each recommendation, the associated probability per year (based on mean values) and uncertainty/error factor are presented. Based on the probability value, the type of recommendations (i.e., test analysis/equipment modification, etc.), the uncertainty, and other factors, a priority ranking from 1 to 10 has been assigned. A ranking of 10 is given to the highest priority recommendations and 1 is given to the less critical recommendations. Recommendations with rankings of 6 to 10 are considered to be crucial and should be implemented or at a minimum critically evaluated. Cost of implementation was not considered in assigning the priority rankings. These rankings are in many ways subjective, but the information in Table 2 should serve as a guide for ARRCOM personnel to determine their own priority rankings for the recommendations.

Final Note

Appendix E to the Priority 1 report is a compilation of incidents that have occurred in explosive and propellant operations in facilities in the United States. The appendix consists of short descriptions of the incidents grouped with regard to the type of process operation involved. The information was extracted from Department of Defense Explosives Safety Board Files under a prior contract conducted for ARRADCOM.

Although the process operations listed are not for demilitarization, many similarities exist. It is suggested that the table be scanned so that the reader obtains a sense for hazardous events that have occurred in the past. In reviewing hazards analyses, people generally are torn between concern for safety and non-belief of scenarios that do not appear credible. It must be remembered that facilities are never designed to include the obvious

hazards. Hazards that remain are generally low probability, requiring several failures to occur. Yet, incidents do occur. It is the function of hazards analysis to minimize the likelihood of such things happening.

TABLE 2. PRIORITIZING THE RECOMMENDATIONS

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10) **
Washout/Steamout North Tower And Refining Building	1. Experiments to Better Characterize Runaway Reaction Conditions	T	7.6	10-34	9
	2. Identify/Evaluate Options to Protect Against Runaway	E	7.6	10-34	8
	3. Move Valves in Vessel Drains Closer to Vessel	E	0.837	∿ 20	7
	4. Evaluate Use of Multiple Thermocouples to Sense Onset Of Runaway	E	7.6	10-34	6
	5. Dump Vessel Content With Existing System At Onset of Runaway	P	7.6	10-34	5
	6. Plastic Tipped Lances In North Tower	E	5×10^{-3}	---	5
	7. Plastic Coated Dipstick For Separator;Keep Dipstick From contamination	E, P	1.8×10^{-3}; 6.2×10^{-2}	---/34	5;6
	8. Prevent Impeller Impact/Scraping After Major Maintenance	P	2.2×10^{-3}	---	5
	9. Inspect To Assure Screen Above Separator Is In Good Condition	P	2.2×10^{-3}	---	4
	10. Evaluate Credibility of Explosive Slug Impact Initiation In Line to Separator	A	ok 7.7×10^{-4}	11	2
	11. Put Vacuum Trap In Line To Vacuum Pump	E	ok 8.8×10^{-7}	---	6
	12. Clean Vessels of Contaminant Prior To Maintenance	P	2.17×10^{-3}	---	4
	13. Clean Contamination On Piping, Etc.	P	(Good Practice)	---	3
	14. Inspect Insulation On Pipes And Vessels For Contamination Getting In Cracks	P	(Good Practice)	---	3
Rotoclone Cleaners And Ductwork	1. Inspect/Clean Ducts Leading To Rotoclone	P	2.17×10^{-3}	---	4
	2. Inspect/Clean Exhaust on Rotoclone	P	2.17×10^{-3}	---	3

* Key For "Type of Recommendation" Column

T - Tests, Experiments
A - Analyses
E - Equipment Modifications
P - Procedure Modifications
C - Comments

** Priority of 1 implies important,
Priority of 10 implies critical

NOTE: if less than 1×10^{-3}/yr, criteria is met.

TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Washout/Steamout South Tower	1. Evaluate Alternate Solutions For Processing Yellow D (Plate Out Problem)	A	2.4×10^{-2}	---	6
	2. Awareness in Yellow D Toxicity During Handling	P	4.76	---	8
	3. Evaluate Emergency Procedure for Transport Container For Yellow D Taken To Bulk Incinerator	P, C	---	---	8
	4. Analyze Structural Integrity Of Floor Grate To Hold Heavy Items	A	(Suggestion)	---	2
Bulk Explosives Disposal Building	1. Determine Compatability of Hydraulic Fluid With Materials To Be Processed	A, T	$<10^{-4}$	---	4
	2. Set Up Compatability Library at WADF	P	$<10^{-4}$	---	6
	3. Determine Potential For Initiation Of Large Pieces Of Explosive Put Into Grinder	T	$<10^{-4}$	---	7
	4. Minimize Potential For Drum Impacts During Transport To Bulk Incinerator	P	$<10^{-4}$	---	3
	5. Install Side Chute/Gate Between Metal Detector And Grinder	E	$<10^{-4}$	---	6
	6. Analyze Structural Integrity of Floor Grate To Hold Grinder During Maintenance	A	$<10^{-4}$	---	3
	7. Decontamination of Grinder Before Maintenance	P	$<10^{-4}$	---	4
Process Water Treatment Plant	1. Determine Potential of Anthracite Coal for Inducing Runaway	T	$<10^{-4}$	---	3
	2. Do Not Use Metal Shovels For Cleaning Sumps, Etc.	P	$<10^{-4}$	---	3
	3. Keep Vessels Flooded With Water/Don't Allow Them To Dry	P	$<10^{-4}$	---	3
Preparation Building	1. Measure Concentration of Solvent Vapors As Cartridge Cases Are Opened	T, E	3.69×10^{-3}	27-31	5
	2. Install System To Monitor Water and Items In Fuze Drop Tanks	G, A	3.2×10^{-2}	∿ 15	4
	3. Do Not Store "Unsafe" Items in Cell 1	P	6.2×10^{-6}	---	6

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Preparation Building (cont.)	4. Robots Expected To Require Frequent Maintenance	C	0.75	24-33	---
	5. Partition In Corridor To Protect Operators From Fragments	E	(Good Practice)		4
	6. Apply Penetrating Oil To Aid In Unscrew Operations	P	(Good Practice)		1
Accumulator	1. Inspect For Leak/Wear In Pinch Valve Rubber Boots	P	1.25×10^{-2}	12	5
	2. Inspect For Conveyor Bearing Failures	P, E	1.95×10^{-4}	---	4
	3. Do Not Adjust Conveyor Rubber Receiving Hopper Too Tight Onto Belt	P	3.5×10^{-5}	---	2
	4. Redundant Bonding For Containers During Filling	P, E.	2.7×10^{-5}	---	6
	5. Prevent Incompatible Dusts In Dust Collector and Vacuum System Ducts	P	2.6×10^{-5}	---	4
	6. Prevent Mixing of Different Propellants For Sale	P	(Good Practices)	---	6
Mechanical Removal Building - Cell 1	1. Drop Impact Tests On Primer Tubes	T	5.8×10^{-5}	15-17	2
	2. Instrumented Shearing Tests	T	8.3×10^{-7}	---	3
	3. Determine Consequence of Initiation of Primer Tubes	T	8.3×10^{-7}	---	3
Mechanical Removal Building - Cell 2	1. References Large Band Saw Recommendations	C	---	---	---
	2. Prevent Initiation Of Head Section Falling Into Tray Or Thrown After Sawing - Modify Fixture	E	13.25	11-26	7
Mechanical Removal Building - Cell 3	1. Inspection/Replacement of Cutters	P	1.3×10^{-5}	---	4
	2. Identify Safe Operating Conditions of Force/Speed For All Items To Be Processed	A, T	1.3×10^{-5}	---	5
	3. Avoid Cutting Into Internal Piping In Items	P	1.3×10^{-5}	---	5
Large Cell C	1. Hazard Associated With Cleaning Fuze After Unscrewing	C, A	---	---	5
Large Cell B	1. Use Conductive Plastic Cover On Sawn Items	P	1.59	13	6
	2. Identify Safe Operating Conditions of Force/Speed For All Items To Be Processed	A, T, P	0.1	17-118	5

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Decontamination Building - Rotary Furnaces	1. Majority Of Hazards Are Equipment Damage	C	---	---	---
	2. Protect Propane Tank From Truck Backing Into It	E,P	3.25×10^{-6}	---	7
Decontamination Building - Tray Type Furnace	1. Inspection For Full Or Partially Full Items Is Important	P	8.28×10^{-3}	32, 122	4
	2. Install Deluge System In Bag Houses	E	6×10^{-4}	10, 14	2
Large Items, Flashing Chamber	1. Comprehensively Inspect Items at First To Assure That Flashing Works Adequately	T	237		8
	2. Use Non-Metal Rakes For Mine Cars	P	7.8×10^{-4}	21	3
	3. Keep Concrete Pad Moist To Prevent ESD	P	1.17	24.27	4
	4. Do Not Use Manual Ignition Of A Powder Train	P	4.7×10^{-2}	9-20	6
	5. Design Bracings For Items In Mine Cars To Assure Items Are Rigidly Fixed In Place	E	1.3×10^{-3}	7-17	4
	6. Train Operators To Distinguish Smokeless Powder From Explosives	P	6.2×10^{-4}	---	6
	7. Determine Criteria For Maximum Quantity of Smokeless Powder To Be Put Into Items	T	1.56×10^{-2}	38	6
	8. Inspect Incoming Items To Assure That A Total Of Less Than 10 Pounds Of Explosive Will Be Flashed	P	1.56×10^{-3}	---	6
	9. Responsibility for Firing Circuit Key and Accountability of Personnel	P	---	---	6
	10. AMC 385-100 Requirements for Cooldowns at Burning Ground	P	---	---	4
Driverless Tractor System, Off Loading Dock, And Magazine	1. Use first DLT trailer as empty spacer for thermal protection during manual operations	P	---	---	1
	2. Arrange Package/Items On DLT Carts With A Low Center Of Mass (i.e., Stable Arrangement)	P	---	---	4
	3. Do Not Use EE Rated DLT's Etc. In Areas With Exposed Explosives Or Volatile Fumes	P	---	---	6
	4. Open Box Car Doors With Care, In Case of Shifted Loads	P	3.5×10^{-2}	32	5

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
General Recommendations	1. Every Operation Covered By Written Procedures	P	---	---	10
	2. Comprehensive Training of Personnel	P	---	---	10
	3. Operators Certified Or Licensed	P	---	---	6
	4. Personnel Tested For Grounding Daily	P	---	---	6
	5. Scheduled Cleanups Of Plant Areas	P	---	---	6
	6. Area Surfaces Kept Wet During Maintenance	P	---	---	5
	7. Two Locker System For Plant Personnel	P, E	---	---	6
	8. Area Entry And Hot Work Permits For All Maintenance	P	---	---	7
	9. During Maintenance Hand Tools Connected To Operators Where Practical	P	---	---	4
	10. Strict Personal Cleanliness Enforced	P	---	---	4
	11. Medical Surveillance Program	P	---	---	6
	12. System Modifications Should Be Hazard Analyzed	A	---	---	6
	13. Compatability Data Library	P, A	---	---	6
	14. Validate Electrostatics Model For Dielectric Surfaces	T, A	---	---	2

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A - Analyses
E - Equipment Modifications
P - Procedural Modifications
C - Comments

** Priority of 1 implies important
Priority of 10 implies critical

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